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BRAKING PERFORMANCE OF A UNITED STATES AIR FORCE FOUR-GROOVE 49--ETC(U)
FEB 81 H DAIUTOLO, C R GRISEL

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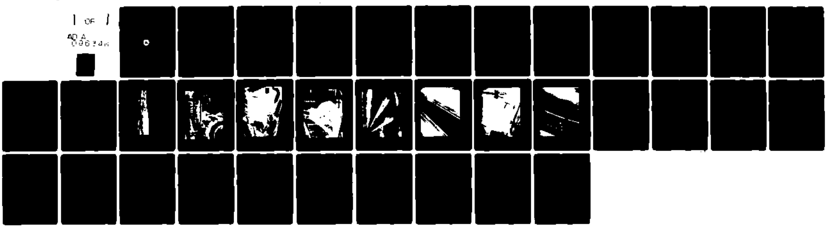

Report No. FAA-RD-80-136
FAA-CT-81-1

LEVEL II

(12)

BRAKING PERFORMANCE OF A UNITED STATES AIR FORCE FOUR-GROOVE 49 × 17 AIRCRAFT TIRE WITH AND WITHOUT SIPES

Hector Daiutolo
Charles Grisel

Prepared by

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
TECHNICAL CENTER
Atlantic City Airport, N.J. 08405

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16. Abstract

Braking tests were conducted to determine if large aircraft tires with laterally-cut sipes in the tread improve the braking performance on a wet surface.

A tire with 1/4-inch deep by 3/16-inch spaced sipes showed improved braking performance over the nonsiped tire when tested on a wet surface. The improvement, however, becomes insignificant when the depth of the sipes is reduced to 1/8-inch, and there is no improvement when standing water is present regardless of the sipe depth.

17. Key Words

Siped Tires
Runway Grooves
Braking Performance
Friction Coefficient
Water Depth

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METRIC CONVERSION FACTORS

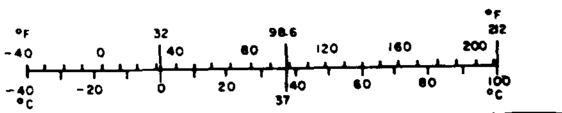
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

The work described herein has been accomplished under a Military Interdepartmental Purchase Request (MIPR) prepared by the U.S. Air Force (USAF) Flight Dynamics Laboratory (FDL) at Wright-Patterson Air Force Base (AFB), Ohio.

The USAF provided program direction, statement of work, and funding as indicated by MIPR #FY1457900032, dated May 1, 1979. The Airport Technology Division, ACT-400, at the Federal Aviation Administration (FAA) Technical Center, conducted the test program and prepared this report. The Naval Air Engineering Center (NAEC) at Lakehurst, New Jersey, provided the test facility and data acquisition under Interagency Agreement DOT-FA WAI-423 between the Airport Development Division of the FAA's Systems Research and Development Service and NAEC.

PURPOSE.

The purpose of this program was to determine whether laterally-cut sipes in an aircraft tire tread improve braking performance on wet or flooded portland cement concrete surfaces.

BACKGROUND.

Improved flight instruments and instrument landing systems have increased the landing frequency of aircraft in adverse weather conditions. A combination of high landing speeds and the presence of water or slush on the runways has resulted in an increase in landing accidents.

For the past year, the Air Force Flight Dynamics Laboratory (AFFDL) Landing Gear Group has been conducting tests to evaluate the effectiveness of laterally-cut sipes in the tire tread. Laboratory dynamometer tests to date have shown that siped-tread tires provide a significant improvement in braking performance under wet conditions; however, it is not known how well these results correlate with tests on wet or flooded concrete runway surfaces. The uncertainty results from the drum curvature effects of the test surface in the laboratory. The FAA test facility located at Lakehurst, New Jersey, has the capability of conducting tests with a 49 x 17 aircraft tire on a flat surface under controlled conditions. It was, therefore, decided to conduct these high-speed track tests prior to aircraft tests on runways. Hence, the AFFDL entered into an agreement with the FAA Technical Center to conduct tests using the USAF standard tread and siped tread, 49 x 17 tires.

TEST FACILITY

The NAEC test facility (track no. 1) was developed jointly by the FAA and the U.S. Navy and has the capability of simulating a jet transport tire-wheel assembly at touchdown and rollout. The setup at the launch end of the track is shown in figure 1. A 4,000-pound test fixture contains the tire-wheel assembly, the dynamometer, and the mechanism required to impart loading and braking to the test wheel. The dynamometer measures the forces that are acting on the test wheel via instrumented strain links. Angular and linear motions of the wheel are also measured. The entire fixture is contained in a 60,000-pound dead load which can be accelerated to speeds of 130 knots by a pusher car containing four jet engines.

The dead load is stopped by an arrestment system at the recovery end of the mile long track. The steel structure for the overhead arrestment of the dead load is shown in figure 2. The loading is applied to the wheel through two hydraulic cylinders that are activated by pressurized nitrogen (figure 3). The vertical load applied in these tests was 39,000 pounds.

The braking system (figure 4) is activated in the same manner as the loading system. Figure 4 also shows the port vertical and horizontal load links. The vertical load links measure the load applied to the wheel, and the horizontal load links measure the braking force between the tire and surface tested. Figure 5 shows the test bed at the recovery end of the track. The bed was a slab 200 feet long, 30 inches wide, and 5 inches thick, consisting of portland cement concrete of 5,000 pounds per square inch (psi) crushing strength. The surface had a broomed finish (figure 6). The average texture depth of the surface was 0.009 inches based on the average of eight grease-smear measurements. The bed was diked by rubber strips into five 40-foot test sections. Dimensional tolerances of the surface for each section were held to within ± 0.16 inch from a perfectly horizontal plane. The first 40 feet were kept dry to insure that the tire was tracking prior to entering the remainder of the test bed.

TIRES.

The tires for these tests were supplied by AFFDL. These were new 49 x 17, 26-ply-rating (PR), four-groove aircraft tires consisting of one standard tread (no siping) (figure 3) and three treads with sipes of the following configurations:

No. 1 - 4/32 inch deep by 3/16 inch spacing

No. 2 - 8/32 inch deep by 3/16 inch spacing (figures 7 and 8)

No. 3 - 8/32 inch deep by 1/8 inch spacing

The No.3 siped tread tire (8/32 inch by 1/8 inch) was not tested.

TEST PROCEDURES

The pusher car engines were started and set at performance levels which would enable the dead-load vehicle to enter the test bed at the desired speed. The system was then released at the launch end of the track. The tire was in contact with the ground (concrete surface) and was in a state of free roll supporting only the 4,000-pound weight of the test fixture for the full mile length of the track. Several hundred feet before the dead load reached the test bed, the pusher car was braked and separated from the dead load. About 150 feet ahead of the test bed, the vertical load was applied to the wheel. The brakes were applied between 50 feet and 20 feet ahead of the test bed depending on the speed of the test. The fully-loaded and braked aircraft wheel then entered the test sections at the desired speed. Loading and brakes were released as the wheel left the test bed.

During testing, each tire was subjected to speeds of 70, 90, 110, and 130 knots. The tire encountered increasing water depths at each successive 40-foot test section. The first 40-foot section, as stated, was kept dry. The second 40-foot section was wet (surface contained water but of no measurable depth). The last three 40-foot sections had average water depths of 0.05, 0.10, and 0.15 inch, respectively. Water depths were measured with the National Aeronautics and Space Administration (NASA) water depth gauge. Tire pressure was held at 170 psi.

Brake pressures were varied, depending on the traction capability of the tire surface condition combination, in order to achieve maximum braking for each set of operating conditions. Maximum

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During testing, each tire was subjected to speeds of 70, 90, 110, and 130 knots. The tire encountered increasing water depths at each successive 40-foot test section. The first 40-foot section, as stated, was kept dry. The second 40-foot section was wet (surface contained water but of no measurable depth). The last three 40-foot sections had average water depths of 0.05, 0.10, and 0.15 inch, respectively. Water depths were measured with the National Aeronautics and Space Administration (NASA) water depth gauge. Tire pressure was held at 170 psi.

Brake pressures were varied, depending on the traction capability of the tire surface condition combination, in order to achieve maximum braking for each set of operating conditions. Maximum

braking was not attempted on the dry surface. Wheel slips, although recorded, were not used to identify maximum braking since they were transient. Free roll represents 0-percent slip; locked wheel, 100-percent slip.

DATA ACQUISITION AND ANALYSIS

Sixty-four tests were run in this series. The most significant variable measured was the friction coefficient, which is the horizontal force between the tire and the concrete surface divided by the vertical load on the wheel. The friction coefficient was measured over the entire length of the test bed and recorded in analog form. These data were averaged over each 40-foot section, reduced to digital form, and separated with respect to the parameters of water depth and standard tire versus siped tire. The friction data were then plotted and curve-fitted with respect to speed. These plots are presented in figures 9 through 12. The actual data points representing maximum braking are also shown. Figures 13 through 15 show the braking performance of each tire in the four surface test conditions. Both siped tires produced slightly higher friction coefficients at a water depth of 0.15 inch than at a water depth of 0.10 inch as noted in figures 14 and 15. A comparison of each tire's braking performance at various speeds and water depths is shown in figure 16. The data used to construct the curves in figures 9 through 16 are contained in tables 1 through 4.

Ten special tests were also conducted. No brake pressure was applied in these tests. Average water depths were held constant over all five 40-foot concrete sections for each test. The purpose of these freewheeling tests was to locate the threshold of hydroplaning with respect to speed and water depth based on the onset of wheel spindown. A freely rotating wheel represents 0-percent spindown and a stationary wheel, 100-percent spindown. Both the standard tire and the 1/4-inch deep by 3/16-inch spacing siped tread tire were subjected to these tests, and the results are shown in figures 17 through 20. Figures 17 and 18 also include braked wheel friction curves derived from figures 9 through 12.

SUMMARY OF RESULTS

The results of the tests are summarized as follows:

1. In the wet condition (no measurable water depth), the 1/4-inch deep by 3/16-inch spacing siped tread tire produced a significant increase in friction coefficient over the standard tread tire (figure 9).

2. In the wet condition, the 1/8-inch deep by 3/16-inch spacing siped tread tire showed only a token increase in friction coefficient over the standard tread tire (figure 9).

3. On surfaces containing standing water (average depths of 0.05, 0.10, and 0.15 inch), neither siped tread tire showed an increase in friction coefficient over the standard tread tire (figures 10, 11, and 12).

4. Although only a limited number of wheel spindown tests were conducted, some evidence of a correlation between braked wheel hydroplaning and unbraked wheel hydroplaning was apparent for the standard tread tire as well as for the 1/4-inch deep by 3/16-inch spacing siped tread tire. For a given tire and speed, braked wheel hydroplaning (friction coefficient approaching 0.05) and unbraked wheel hydroplaning (onset of wheel spindown) appeared to occur over the same water depth range (figures 17 and 18).

5. Inability of the 1/4-inch deep by 3/16-inch spacing siped tread tire to outperform (resistance to hydroplaning) the standard tread tire on surfaces containing standing water was again apparent in the unbraked wheel spindown data (figures 17, 19, and 20). The average water depths were 0.15, 0.20, and 0.25 inch.

CONCLUSIONS

1. A four-groove 49 x 17 aircraft tire with 1/4-inch deep by 3/16-inch spaced sipes when compared to a nonsiped tire exhibits improved braking performance on a portland cement concrete surface under the wet condition (surface water of no measurable depth).

2. The improvement in braking performance is insignificant when the sipes are reduced to a 1/8-inch depth.

3. Sipes at either depth offer no improvement in braking performance when the tire encounters standing water.

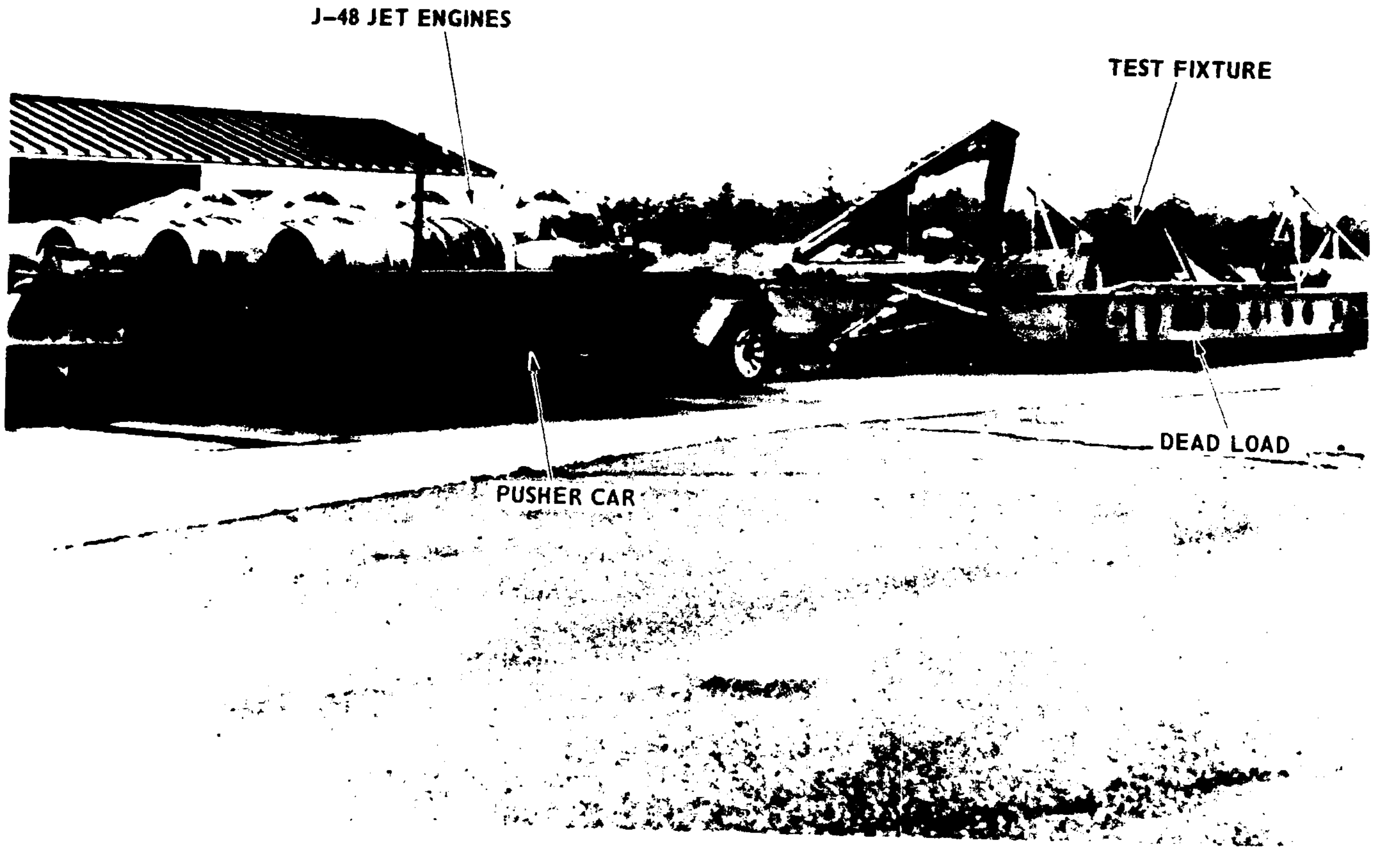

FIGURE 1. TEST SYSTEM AT LAUNCH END OF TRACK

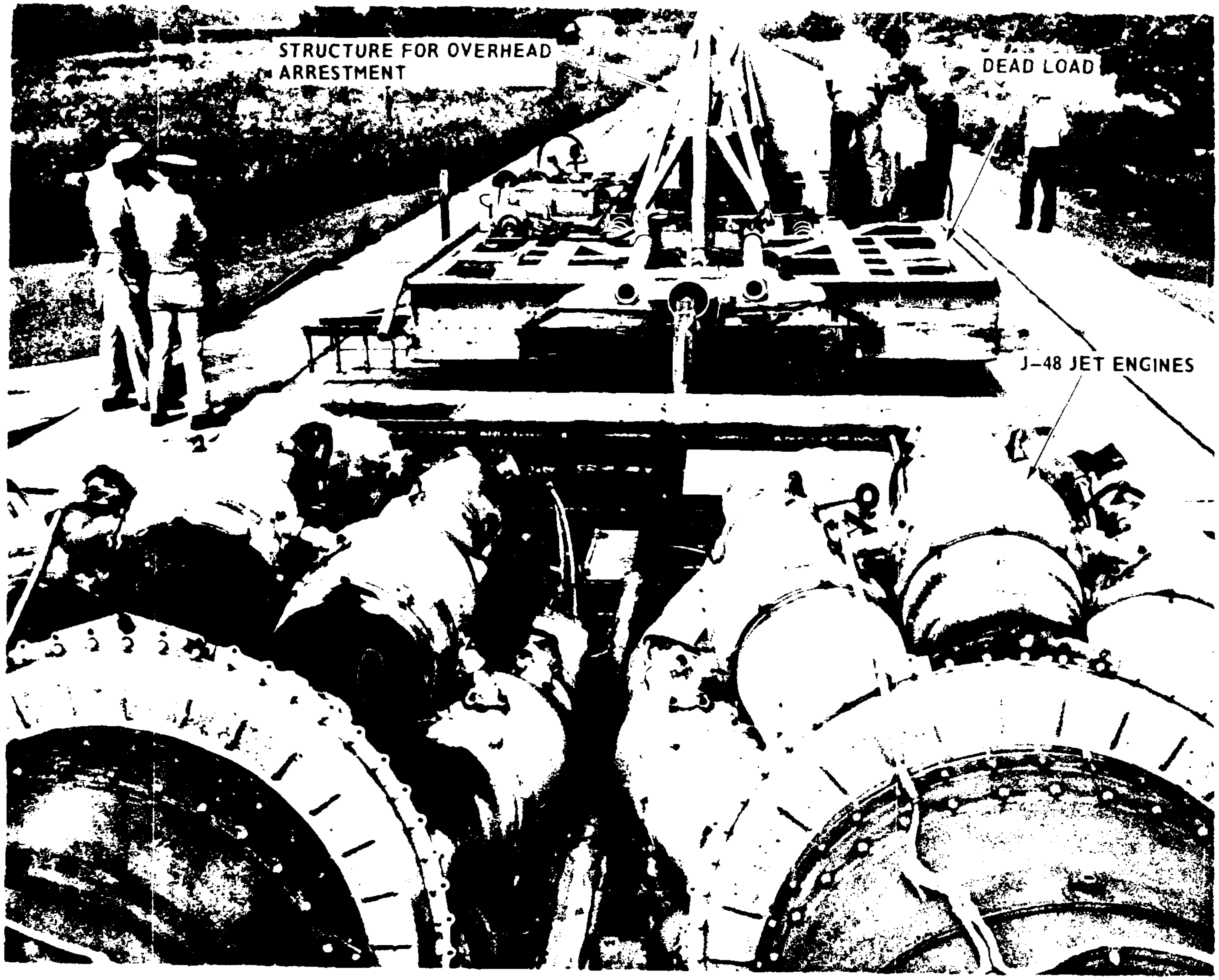

FIGURE 2. VIEW DOWNTRACK FROM LAUNCH END

FIGURE 3. STANDARD TREAD 49 x 17 AIRCRAFT TIRE POSITIONED IN TEST FIXTURE

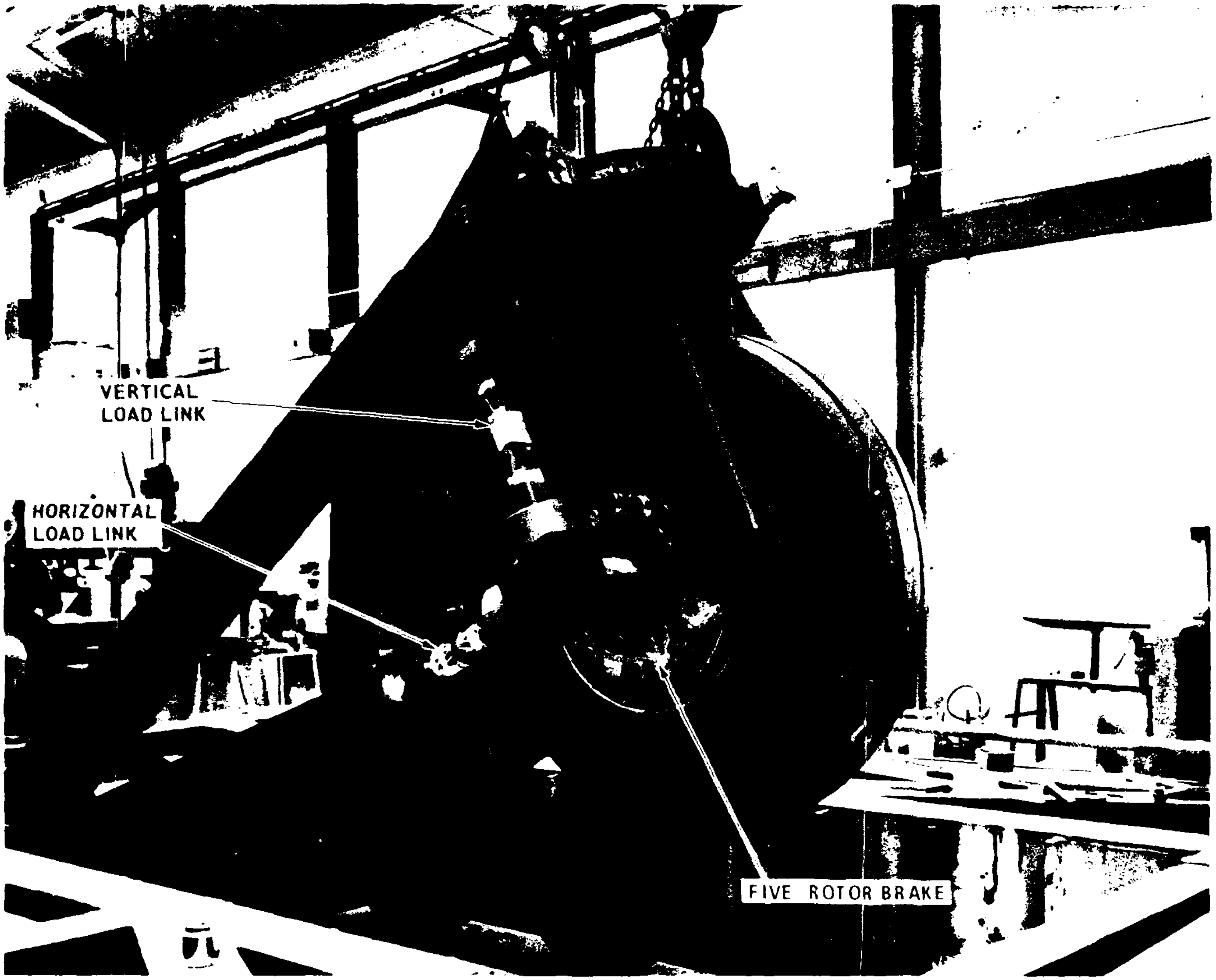

FIGURE 4. DETAIL OF BRAKE AND LOAD LINKS

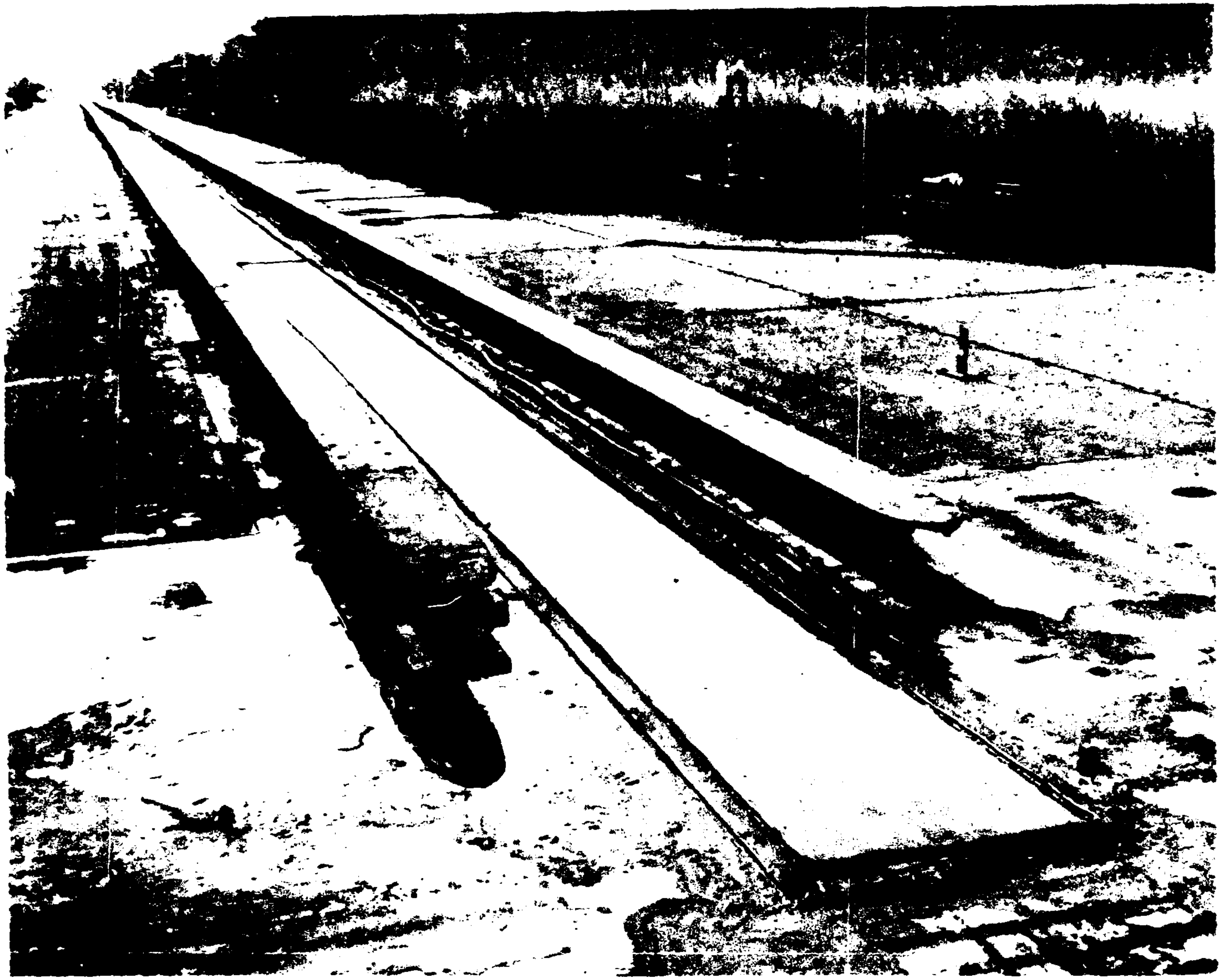

FIGURE 5. PORTLAND CEMENT CONCRETE TEST BED LOOKING UPTRACK

FIGURE 6. PORTLAND CEMENT CONCRETE TEST SURFACE WITH BROOMED FINISH

FIGURE 7. SIPED TREAD 49 x 17 AIRCRAFT TIRE POSITIONED IN TEST FIXTURE

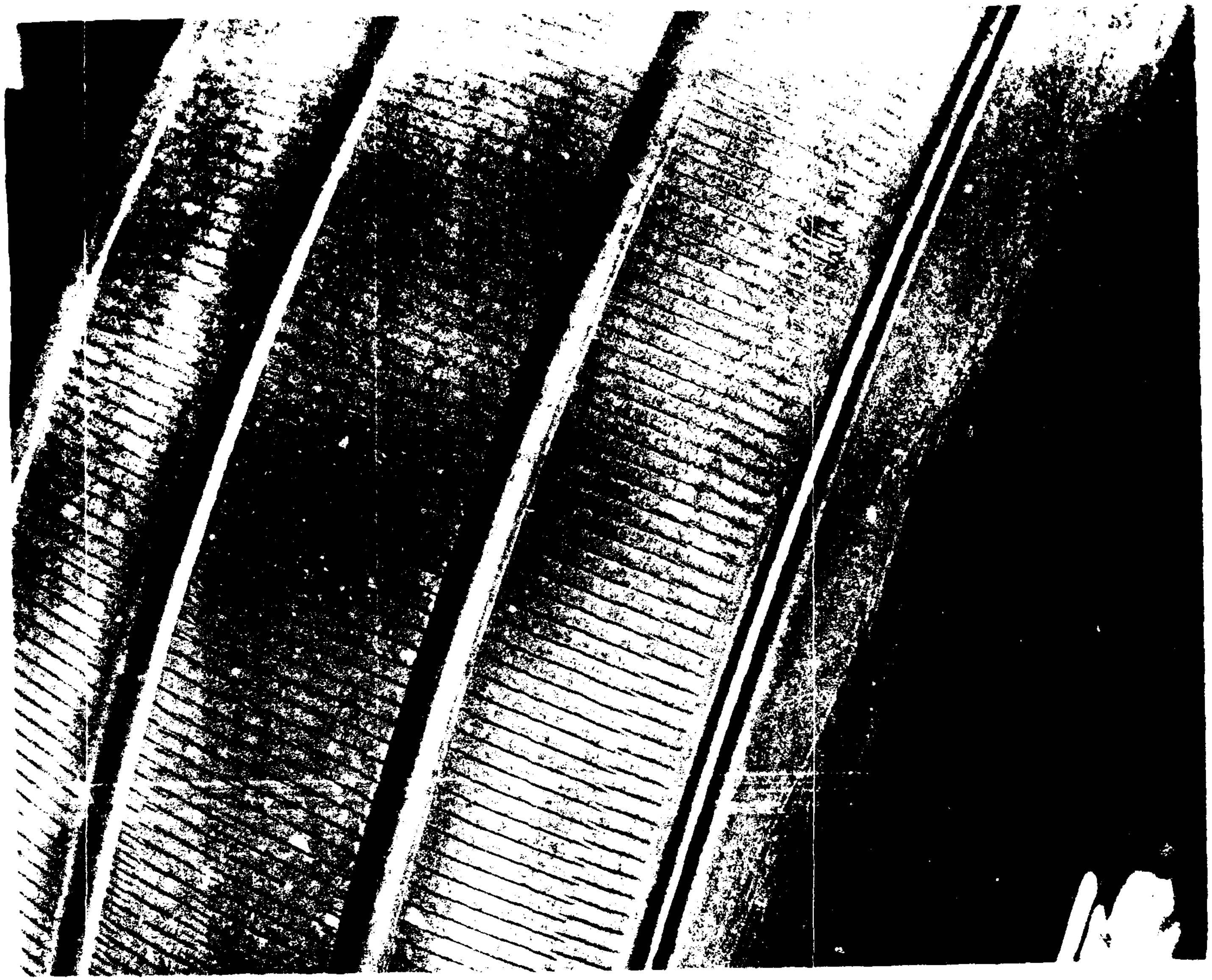

FIGURE 8.   DETAIL OF SIPES SPACED AT 3/16 INCH

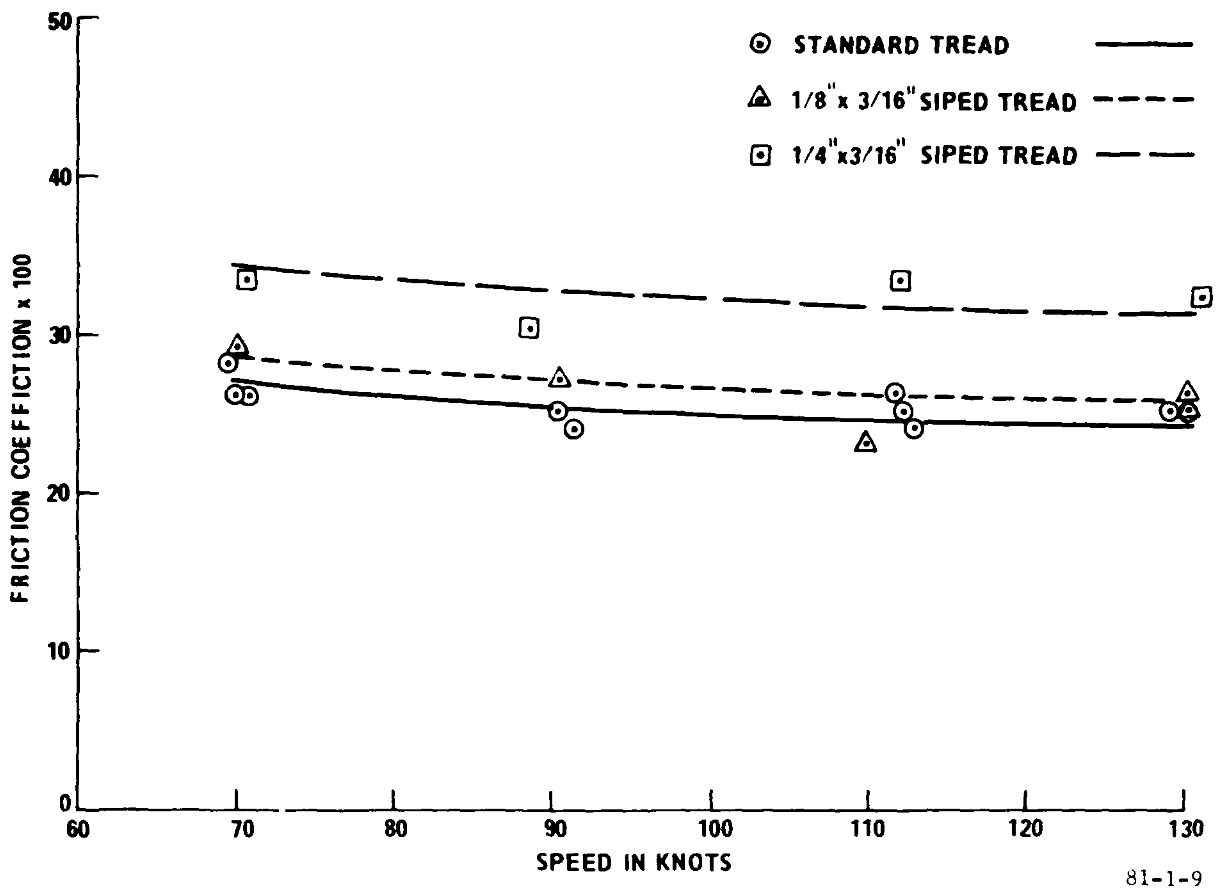

FIGURE 9. BRAKING PERFORMANCE OF FOUR-GROOVE 49 X 17 AIRCRAFT TIRES ON PORTLAND CEMENT CONCRETE; AVERAGE WATER DEPTH 0.00 INCH (WET)

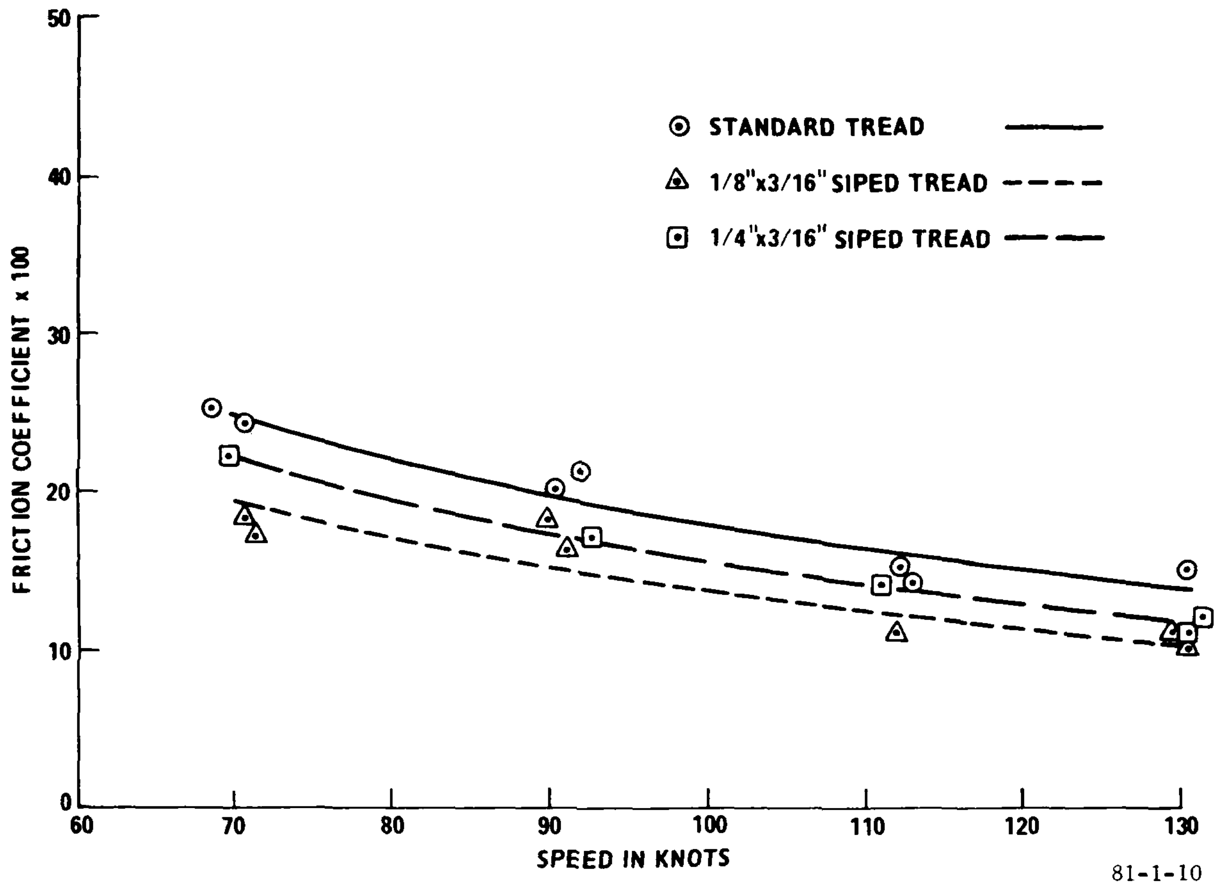

FIGURE 10. BRAKING PERFORMANCE OF FOUR-GROOVE 49 X 17 AIRCRAFT TIRES ON PORTLAND CEMENT CONCRETE; AVERAGE WATER DEPTH 0.05 INCH

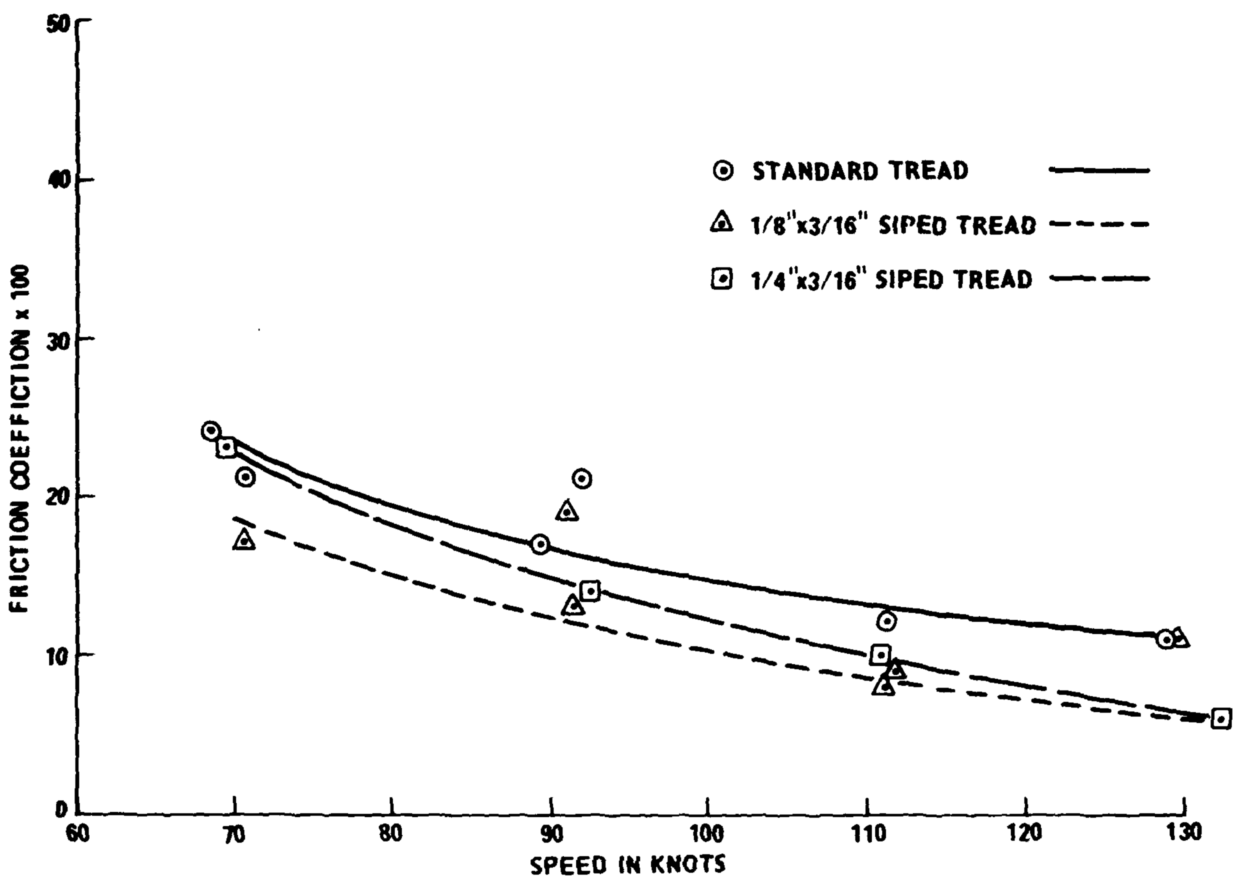

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FIGURE 11. BRAKING PERFORMANCE OF FOUR-GROOVE 49 X 17 AIRCRAFT TIRES ON PORTLAND CEMENT CONCRETE; AVERAGE WATER DEPTH 0.10 INCH

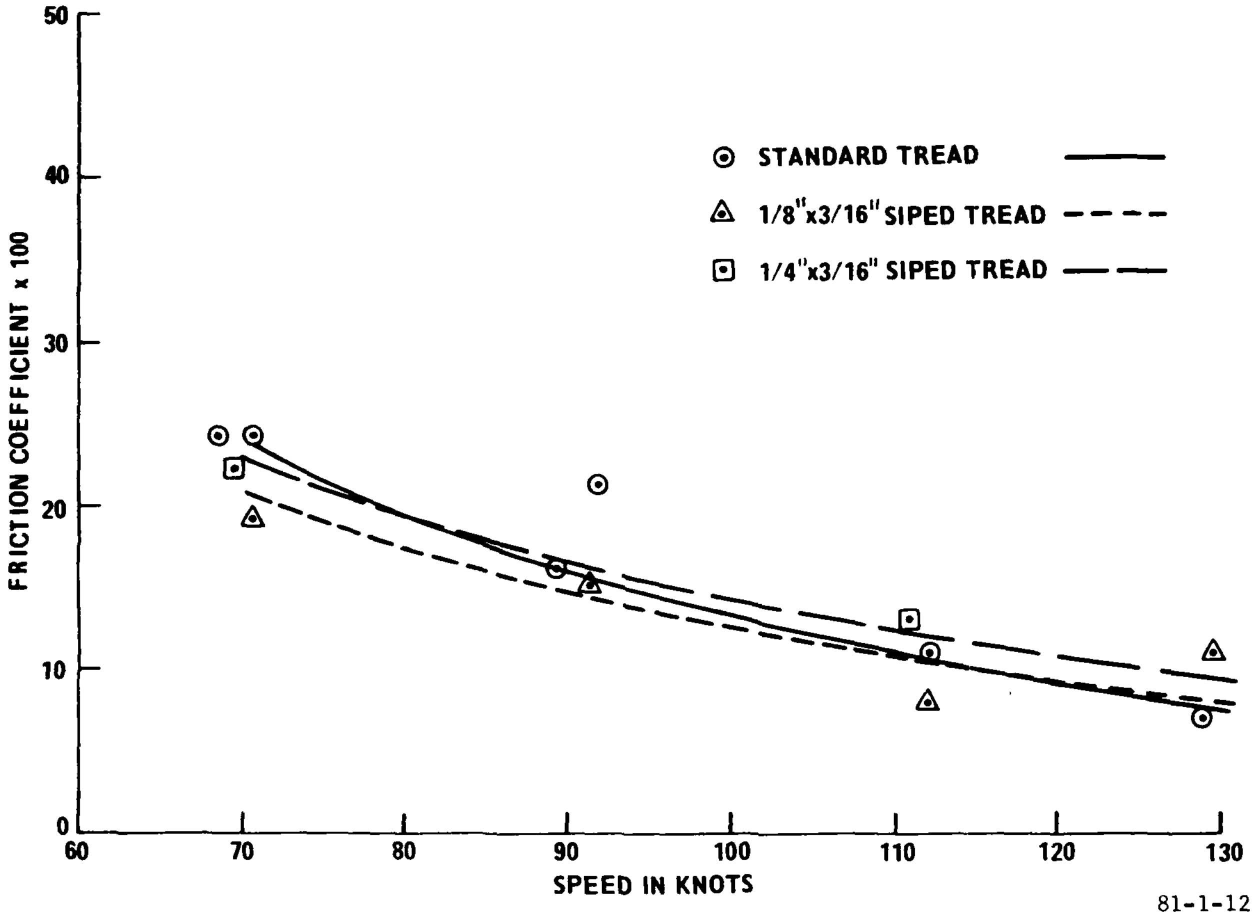

FIGURE 12. BRAKING PERFORMANCE OF FOUR-GROOVE 49 X 17 AIRCRAFT TIRES ON PORTLAND CEMENT CONCRETE; AVERAGE WATER DEPTH 0.15 INCH

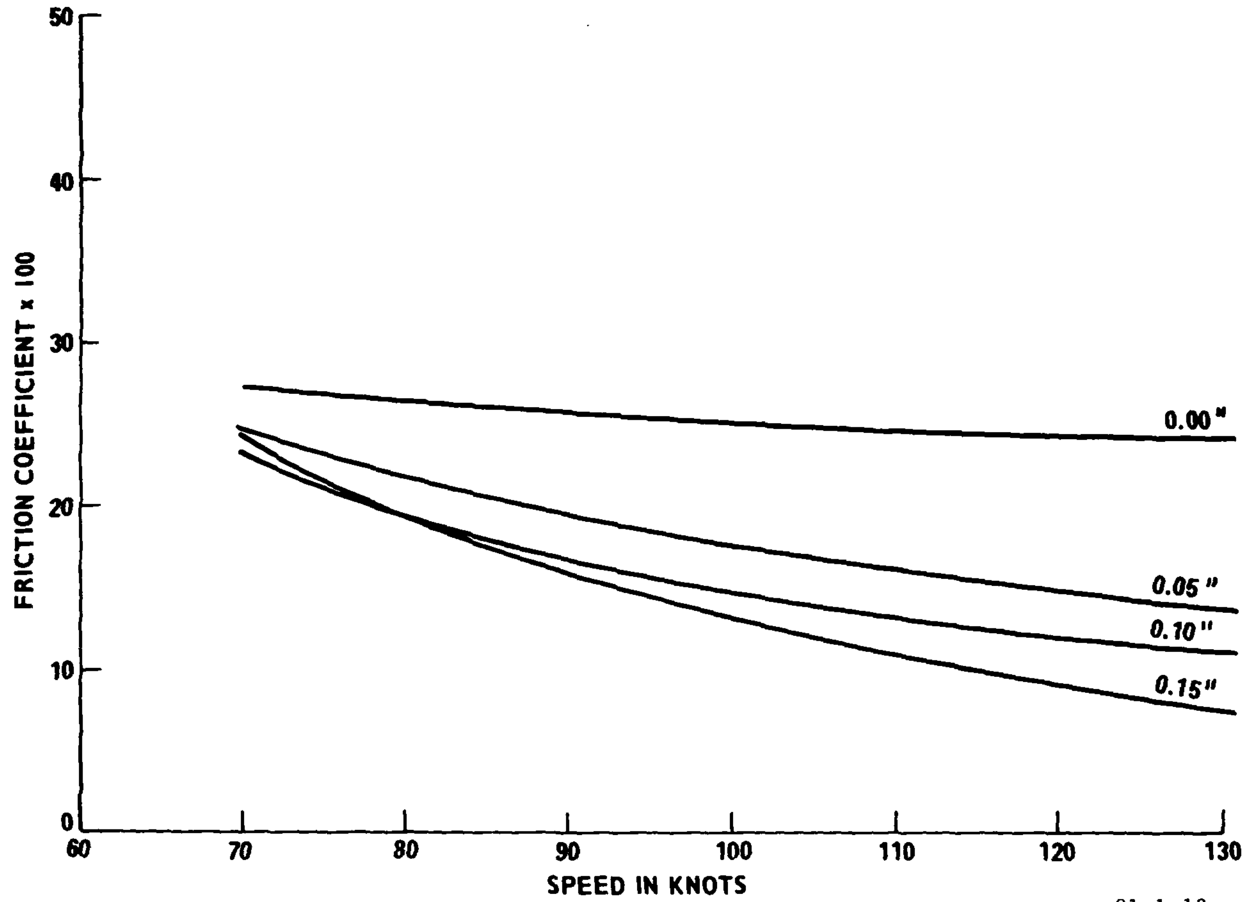

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FIGURE 13. *BRAKING PERFORMANCE OF FOUR-GROOVE 49 X 17 STANDARD TREAD AIRCRAFT TIRES ON PORTLAND CEMENT CONCRETE; WATER DEPTHS OF 0.00, 0.05, 0.10, AND 0.15 INCH*

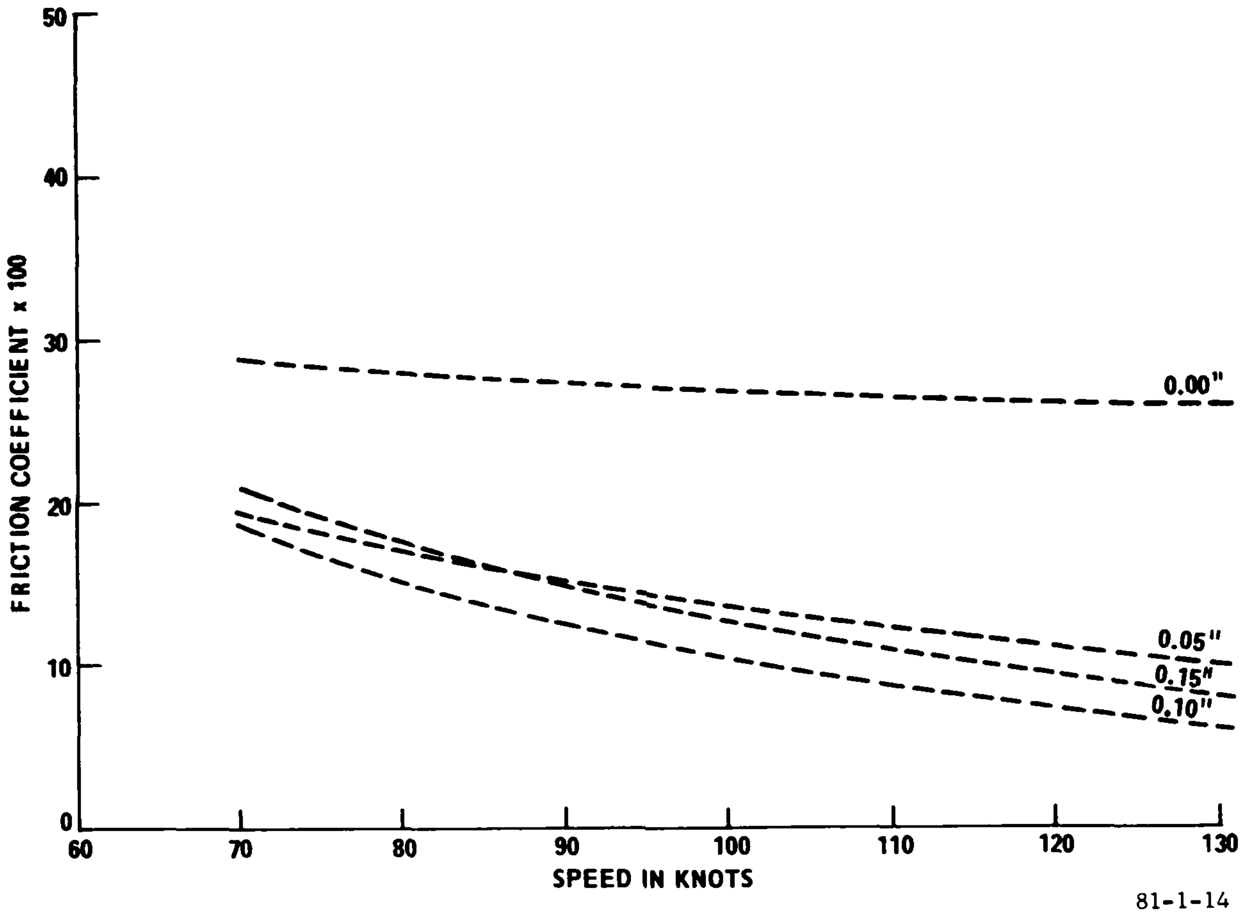

FIGURE 14. BRAKING PERFORMANCE OF FOUR-GROOVE 49 X 17, 1/8-INCH X 3/16-INCH SIPED TREAD AIRCRAFT TIRES ON PORTLAND CEMENT CONCRETE; WATER DEPTHS OF 0.00, 0.05, 0.10, AND 0.15 INCH

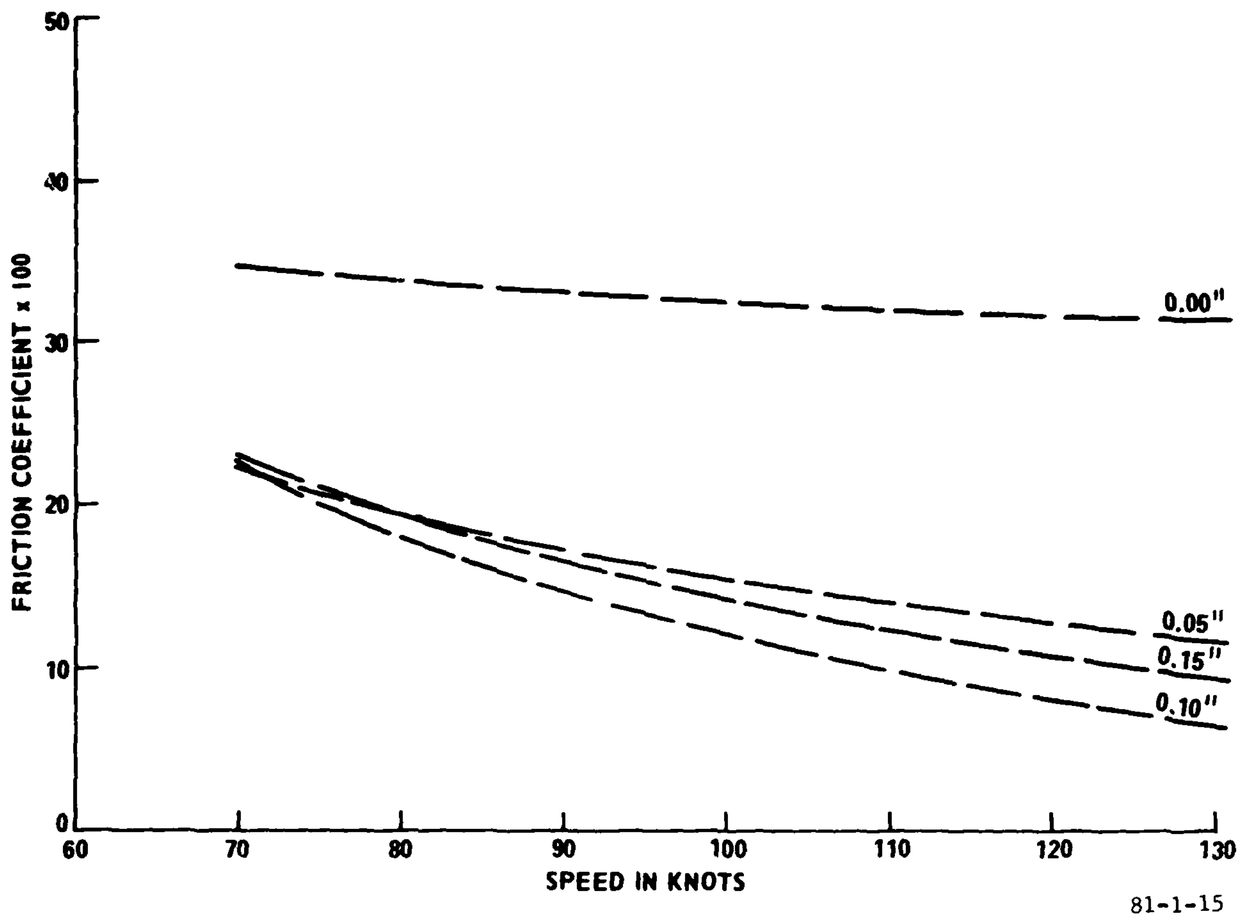

FIGURE 15. BRAKING PERFORMANCE OF FOUR-GROOVE 49 X 17, 1/4-INCH X 3/16-INCH SIPED TREAD AIRCRAFT TIRES ON PORTLAND CEMENT CONCRETE; WATER DEPTHS OF 0.00, 0.05, 0.10, AND 0.15 INCH

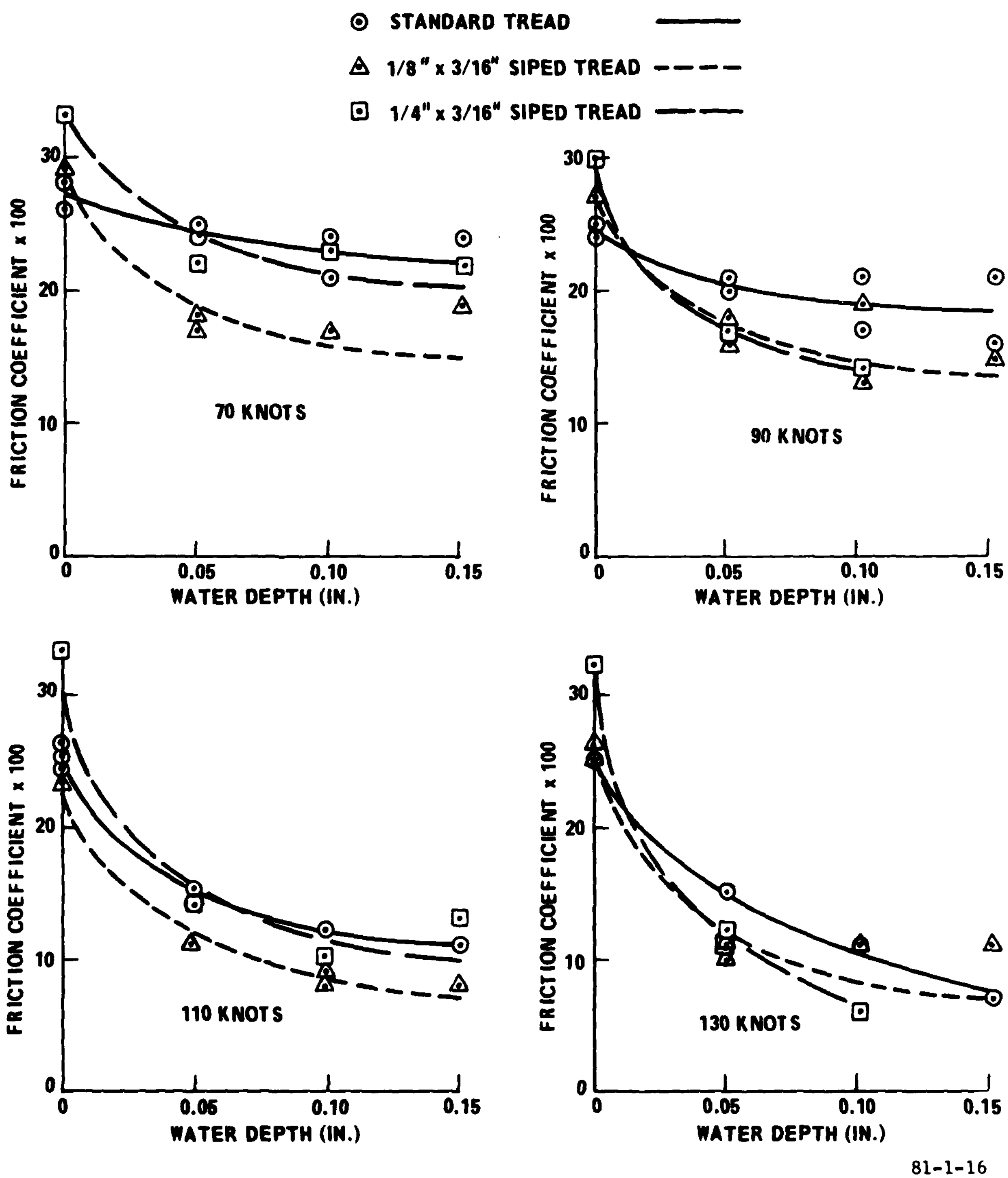

FIGURE 16. BRAKING PERFORMANCE OF FOUR-GROOVE 49 X 17 AIRCRAFT TIRES ON PORTLAND CEMENT CONCRETE AT VARIOUS SPEEDS AND WATER DEPTHS

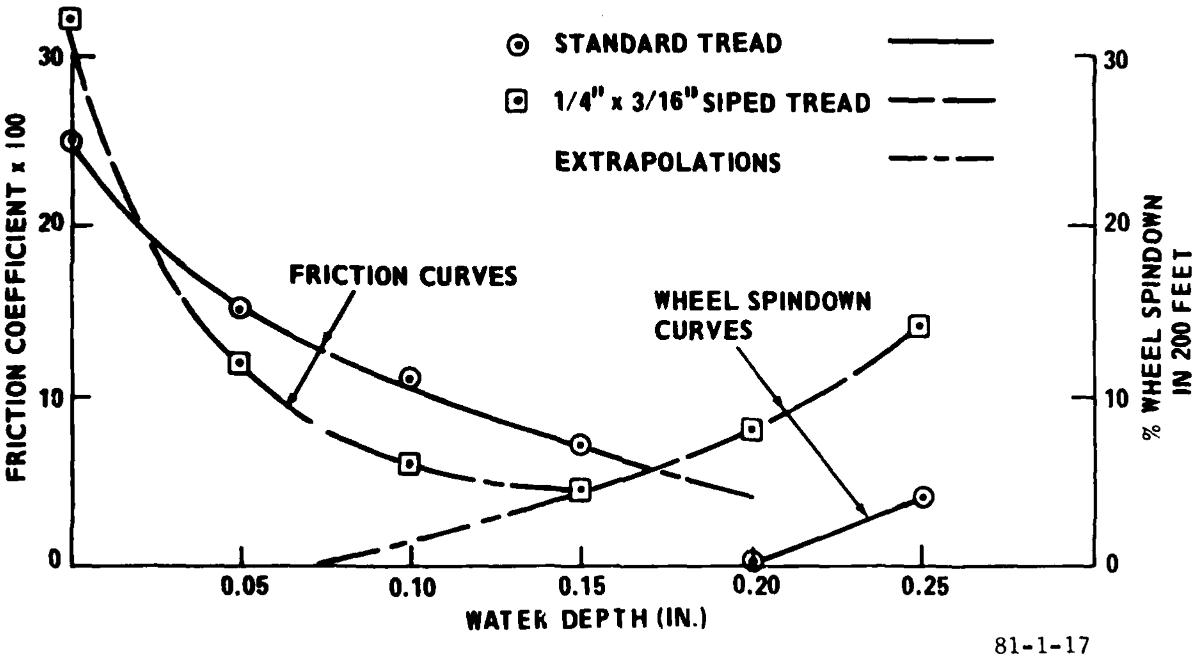

FIGURE 17. RELATIONSHIP BETWEEN BRAKED WHEEL HYDROPLANING AND UNBRAKED WHEEL HYDROPLANING OF A FOUR-GROOVE 49 X 17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE; SPEED, 130 KNOTS

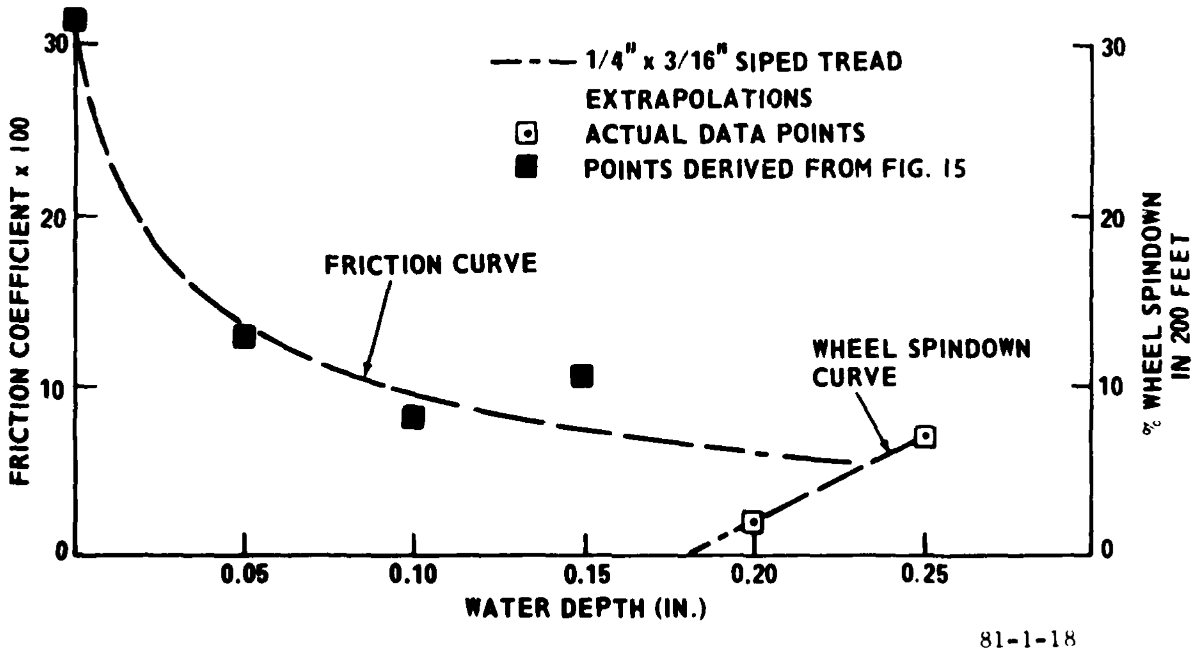

FIGURE 18. RELATIONSHIP BETWEEN BRAKED WHEEL HYDROPLANING AND UNBRAKED WHEEL HYDROPLANING OF FOUR-GROOVE 49 X 17 AIRCRAFT TIRES ON PORTLAND CEMENT CONCRETE; SPEED, 120 KNOTS

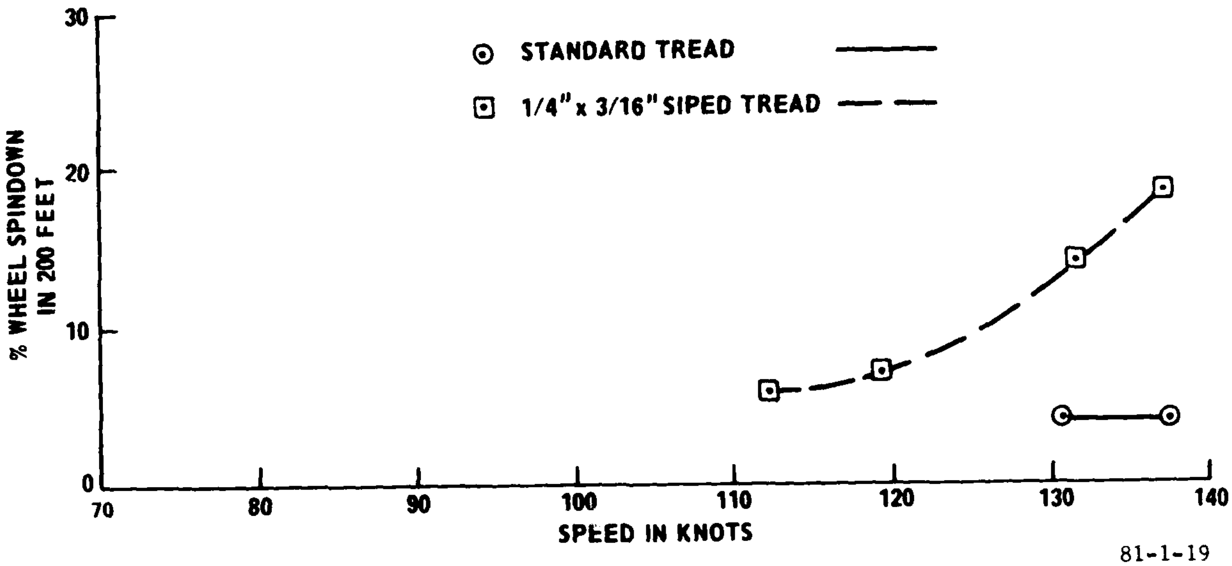

FIGURE 19. UNBRAKED WHEEL HYDROPLLANING OF A FOUR-GROOVE 49 X 17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE; AVERAGE WATER DEPTH 0.25 INCH

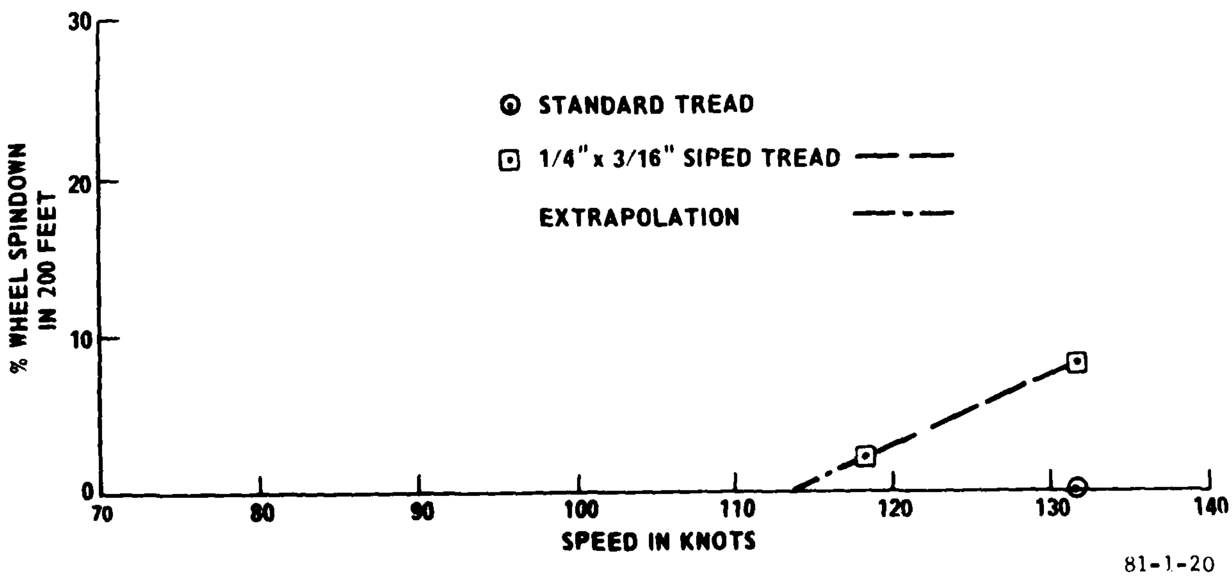

FIGURE 20. UNBRAKED WHEEL HYDROPLLANING OF A FOUR-GROOVE 49 X 17 AIRCRAFT TIRE ON PORTLAND CEMENT CONCRETE; AVERAGE WATER DEPTH 0.20 INCH

TABLE 1. WATER DEPTH, 0.00 INCH (WET)

Test No.	Speed (Knots)	Brake Pressure	Friction Coefficient x 100	Tire Type
13989	70	1100	28	Standard Tread
13983	70	1100	26	Standard Tread
13990	71	800	26	Standard Tread
13923	90	800	25	Standard Tread
13991	91	1000	24	Standard Tread
13931	111	800	26	Standard Tread
13994	112	800	25	Standard Tread
13993	112	700	24	Standard Tread
13984	129	900	25	Standard Tread
13985	130	1150	25	Standard Tread
13950	70	1000	29	Siped Tread
				1/8" x 3/16"
13938	90	1200	27	1/8" x 3/16"
13942	110	850	23	1/8" x 3/16"
13947	130	950	26	1/8" x 3/16"
13946	130	800	25	1/8" x 3/16"
13957	71	1500	33	Siped Tread
				1/4" x 3/16"
13959	88	1200	30	1/4" x 3/16"
13960	112	1350	33	1/4" x 3/16"
13961	130	1200	32	1/4" x 3/16"

TABLE 2. WATER DEPTH, 0.05 INCH

Test No.	Speed (Knots)	Brake Pressure	Friction Coefficient x 100	Tire Type
13981	69	900	25	Standard Tread
13990	71	800	24	Standard Tread
13923	90	650	20	Standard Tread
13922	92	800	21	Standard Tread
13994	112	800	15	Standard Tread
13993	112	700	14	Standard Tread
13928	130	500	15	Standard Tread
13951	71	650	18	Siped Tread
				1/8" x 3/16"
13952	71	800	17	1/8" x 3/16"
13934	90	800	18	1/8" x 3/16"
13935	91	500	16	1/8" x 3/16"
13939	111	400	11	1/8" x 3/16"
13944	129	200	11	1/8" x 3/16"
13943	130	500	10	1/8" x 3/16"
				Siped Tread
13963	70	700	22	1/4" x 3/16"
13971	92	700	17	1/4" x 3/16"
13953	110	600	14	1/4" x 3/16"
13967	130	500	11	1/4" x 3/16"
13966	130	650	12	1/4" x 3/16"

TABLE 3. WATER DEPTH, 0.10 INCH

Test No.	Speed (Knots)	Brake Pressure	Friction Coefficient x 100	Tire Type
13981	69	900	24	Standard Tread
13990	71	800	21	Standard Tread
13921	89	600	17	Standard Tread
13922	92	650	21	Standard Tread
13927	111	300	12	Standard Tread
13929	128	350	11	Standard Tread
				Siped Tread
13951	71	650		1/8" x 3/16"
13935	91	500	19	1/8" x 3/16"
13936	91	400	13	1/8" x 3/16"
13940	111	200	08	1/8" x 3/16"
13939	111	400	09	1/8" x 3/16"
13944	129	200	11	1/8" x 3/16"
				Siped Tread
13963	70	700	23	1/4" x 3/16"
13971	92	700	14	1/4" x 3/16"
13953	110	600	10	1/4" x 3/16"
13968	132	400	06	1/4" x 3/16"

TABLE 4. WATER DEPTH, 0.15 INCH

Test No.	Speed (Knots)	Brake Pressure	Friction Coefficient x 100	Tire Type
13981	69	900	24	Standard Tread
13990	71	800	24	Standard Tread
13921	89	600	16	Standard Tread
13922	92	650	21	Standard Tread
13927	110	300	11	Standard Tread
13929	128	350	07	Standard Tread
				Siped Tread
13951	71	650	19	1/8" x 3/16"
13936	91	400	15	1/8" x 3/16"
13940	111	200	08	1/8" x 3/16"
13944	129	200	11	1/8" x 3/16"
				Siped Tread
13963	70	700	22	1/4" x 3/16"
13953	110	600	13	1/4" x 3/16"